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Judgement and Decision Making in Dynamic Tasks

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>This research note presents a theory of task conditions on the grounds that such a theory is a prerequisite for studying dynamic decision making. The principal features of the theory are: a) a task-cognition inducement principle, b) a distinction drawn between surface and depth characteristics of tasks, and c) a task continuum index. Also presented is a theory of cognition in dynamic tasks, the main features of which are a cognitive continuum index set in parallel with the continuum index, and a description of the role of pattern seeking and functional-relation seeking in dynamic tasks. The practical consequences for both designers and operators are indicated.

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JUDGMENT AND DECISION MAKING IN DYNAMIC TASKS

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Abstract

A theory of task conditions is presented on the ground that such a theory is a prerequisite for studying dynamic decision making. The principal features of the theory are (a) a task-cognition inducement principal, (b) a distinction drawn between surface and depth characteristics of tasks, and (c) a task continuum index. Also presented is a theory of cognition in dynamic tasks, the main features of which are (a) a cognitive continuum index set in parallel with the task continuum index, and (b) a description of the role of pattern seeking and functional-relation seeking in dynamic tasks. The practical consequences for both designers and operators are indicated.

Judgment and Decision Making in Dynamic Tasks

A recent study by the librarian at the Center for Research on Judgment and Policy (University of Colorado, Boulder) showed that in 1987 articles on judgment and decision making appeared in nearly 1000 different journals. Despite the wide variety of research that such a figure documents, judgment and decision making in dynamic tasks has hardly been touched; virtually all the research has focussed on static tasks. Thus, we are like explorers, carrying impressive equipment that has been widely tested in one territory, who are now about to test it in a new territory. We begin with a theory of task systems.

A Theory of Dynamic Tasks

Theories of cognitive systems abound, but theories of task systems hardly exist. Without a theory of task (or environmental) systems, however, it is impossible to know how to apply or generalize the results of any given study. If Jones finds, say, a surprising result in one situation, how can Smith decide whether s/he should expect to find it in another? Psychological theory has been particularly deficient in this regard because it is still bound in large measure to a single "stimulus" as a representative of environmental systems. And psychological research strategy is still limited by its use of research methods that isolate such "stimuli" in the context of research designs originally developed for the purpose of testing agricultural "treatments," a deficiency noted decades ago by Brunswik (1956) and Newell and Simon (1972). Without a general theory of task systems that goes far beyond stimulus-response psychology

and that specifies significant task properties and functions, research results become situation-specific, the literature expands without end, books get larger rather than smaller, and the research investment must be spread thinner and thinner. The present theory thus addresses the critical need for a theory of task systems. It has three principal features: (a) a task inducement principle, (b) the separation of surface and depth aspects of task systems, and (c) a task continuum on which any task can be placed.

Principal Features of a Theory of Task Systems

Feature 1: The inducement principle. Task systems induce, but do not compel, the subject to employ a form of cognition compatible with the system. Task-cognition compatibility arises because task conditions offer greater support for one form of cognition over another. For example, a task that offers information in terms of numbers, or logical symbols, and permits considerable time for calculation offers greater support for analytical cognition than a task that offers the same information in terms of a picture and allows a brief time for a judgment, which, in turn, will offer greater support for intuitive cognition.

Task conditions, however, do not compel the subject to employ the form of cognition that is offered the greatest support by the task. Numbers can produce hasty, intuitive judgments based on a minimum of analysis, and pictures can become the subject of endless analysis. Extreme circumstances aside, however, the theory argues that task conditions induce corresponding cognitive conditions. That premise raises two empirical questions: (a) Does that in fact happen? and (b) Does the cognitive activity that

corresponds to that induced by task conditions provide greater judgmental accuracy than cognition that does not correspond to that induced by the task? Hammond, Hamm, Grassia, and Pearson (1987) offer some evidence that such task-cognition correspondence is indeed induced, and that it does lead to greater accuracy in judgment, although far more research is required.

Feature 2: Depth and surface features of tasks. Engineers ordinarily design the structures and functions of dynamic task systems (here called depth features) with great care because the system must work. The depth features of a system are usually hidden from, and often incomprehensible to, the operators of the system. The representation of the depth features (here called surface features) are those which the operator sees. But such displays of information about the depth state of the system are seldom, if ever, designed with a clear understanding of the cognitive activity that the surface features will induce in the operator. (See Rasmussen, Duncan, & Leplat, 1987, who present new considerations of this topic with particular reference to the generation of errors.)

Modern technology will permit information to be displayed in almost any way for any task system, thus providing the design engineer with many choices for displaying information about the task system, but this choice has generally been exercised in an arbitrary way. Arbitrariness should not be surprising, however, for no one can be certain exactly what the relations between task displays and cognitive activity are. Although it is now being realized that design (depth) "logic" will ordinarily be different from operator (surface) "logic" (Brehmer, 1987a; de Montmollin and De Keyser, 1986; Rasmussen, 1983, 1985), the exact differences in these

"logics" are far from being well understood. (See Rasmussen and Vicente, 1987, who address this matter from both engineering and psychological points of view by examining the "ecological interface design" [p. 22 ff]; note also their description of the problem, "making visible the invisible" [p. 23].)

In short, both the nature of the task system itself (its depth characteristics) and the manner in which those characteristics are displayed to the subject (its surface characteristics) need to be examined in relation to the mode of cognitive activity they induce in the operator of the system. The next feature of the theory indicates how this may be achieved.

Feature 3: The Task Continuum Index (TCI). Both the surface and depth features of task systems can be ordered on a task continuum that ranges from analysis inducement to intuition inducement. Because of the inducement principle, knowledge of the locus of a task on the TCI by the designer should make it possible to predict the corresponding cognitive behavior on the part of the operator. In order to make this prediction concrete, a definition of tasks must be developed so that they can be ordered on the TCI from analysis inducing to intuition inducing. The properties of tasks that define the poles of the TCI are listed in Table 1. It thus becomes possible to disconfirm a principal feature of the theory, namely, that task conditions induce corresponding cognitive activity. That is, a task that is described in terms of the attributes indicated in Table 1 to be analysis-inducing should in fact induce analytical cognition. The same holds, of course, for any task locus defined in terms of the TCI.

Insert Table 1 about here

Describing corresponding cognitive activity, however, requires that cognitive activity also be defined. Therefore, we turn now to a theory of cognition.

A Theory of Cognition for Dynamic Tasks

Principal Features of a Theory of Cognition

Feature 1: A cognitive continuum. Cognition is also defined in terms of a continuum that moves from analysis to intuition. An index--the Cognitive Continuum Index (CCI)--can be used to place any cognitive activity that exhibits the appropriate properties at a specific point on the continuum. The terms used to anchor the poles of this index are presented in Table 2. Examples of specific calculations can be found in Hammond et al., 1987.

Insert Table 2 about here

Feature 2: The correspondence-accuracy principle. This principle argues that when cognitive activity is found to correspond to task properties (i.e., when the locus of cognitive activity on the CCI matches the locus of the task on the TCI), judgmental accuracy will be greater than when cognitive activity does not correspond to task conditions. Once task properties are defined so that it is possible to locate any task on the TCI, and cognitive activity becomes sufficiently defined to locate it on

the CCI, then it becomes possible to test both propositions and to test the generality of the theory across task systems. Thus, for example, in a study of highway engineers, Hammond et al. (1987) found that task-cognition correspondence did lead to greater judgmental accuracy across nine conditions.

If that conclusion is found to be generally true, then the operator who employs analytical cognition in response to task information displayed in a manner designed to induce analytical cognition will be more accurate in his/her judgments than if s/he engaged in (noncorresponding) intuitive cognition. That proposition seems common sensical, but the parallel conclusion regarding intuition defies common sense. For the parallel conclusion argues that the operator who employs intuitive judgment in response to task information designed to evoke intuitive cognition will be more accurate in his/her judgments than one who is analytical in these circumstances. Not only does this conclusion defy common sense, but it runs counter to current research-based suppositions, all of which argue in favor of the application of analytical solutions in all circumstances (Kahneman, Slovic, & Tversky, 1982).

<u>Feature 3: Changes in cognition induced by changes in the properties of task systems</u>. Cognition will change in two ways as function of task changes: (a) Its location on the cognitive continuum will change, and (b) it will shift from pattern seeking to functional-relation seeking and vice versa. Each is discussed in turn.

Task Change and Movement on the Cognitive Continuum

In static tasks changes in cognition are induced by failure. Although the location of cognitive activity will be induced by task properties in static tasks, movement on the cognitive continuum from analysis to intuition (or the reverse) will be induced by failure to solve a problem. Thus, for example, if a quick, intuitive judgment (or series of judgments) results in failure (wrong answers), the subject will be induced to resort to whatever analytical resources s/he may possess in order to "reason it out." On the other hand, if an analytical approach fails, subjects will be induced to guessing at situations (e.g., "let's try this") even though it is recognized that the guess cannot be fully supported by analytical efforts. In a classical passage, the philosopher Pepper described this cognitive activity as cyclical, thus:

> This tension between common sense and expert knowledge, between cognitive security without responsibility and cognitive responsibility without full security, is the interior dynamics of the knowledge situation. The indefiniteness of much detail in common sense, its contradictions, its lack of established grounds, drive thought to seek definiteness, consistency, and reasons. Thought finds these in the criticized and refined knowledge of mathematics, science, and philosophy, only to discover that these tend to thin out into arbitrary definitions, pointer readings, and tentative hypotheses. Astounded at the thinness and hollowness of these culminating achievements of conscientiously responsible cognition, thought seeks matter for

> its definitions, significance for its pointer readings, and support for its wobbling hypotheses. Responsible cognition finds itself insecure as a result of the very earnestness of its virtues. But where shall it turn? It does, in fact, turn back to common sense, that indefinite and irresponsible source which it so lately scorned. But it does so, generally, with a bad grace. After filling its empty definitions and pointer readings and hypotheses with meanings out of the rich confusion of common sense, it generally turns its head away, shuts its eyes to what it has been doing, and affirms dogmatically the self-evidence and certainty of the common-sense significance it has drawn into its concepts. Then it pretends to be securely based on self-evident principles or indubitable facts.... Thus the circle is completed. Common sense continually demands the responsible criticism of refined knowledge, and refined knowledge sooner or later requires the security of common-sense support. (Pepper, 1948, pp. 22-23)

<u>In dynamic tasks changes in cognition are induced by changes in task properties</u>. In dynamic tasks, failure is not required for cognitive change to occur (as in the case of static tasks); movement on the cognitive continuum will be induced by changes in task properties--depth and/or surface--over time. Specifically, movement will be induced by a change in the location of the surface and/or depth properties of the task on the TCI. Thus, for example, at t0 the task properties may be highly analysis inducing, but the subsequent task properties present at t1 may induce

intuition. Of course, not all of the properties of a task system need change at any given time. Because the locus of a task on the TCI is affected by several task properties, the locus of a task on the TCI can be changed in a number of ways. Predictability of the locus of cognitive activity on the CCI is achieved because of the intersubstitutability principle. That is, changes in task properties have equal impact on the calculation of the locus of a task on the TCI, and, therefore, change in one task property is intersubstitutable with any change in any other. Thus change in the locus of cognitive activity on the CCI is a linear function of change in the locus of a task on the TCI.

Quasirationality. The concept of a cognitive continuum means that cognition need not be either intuitive or analytical but may possess some properties of both. If, for example, cognition can be described as being located at some point midway on the CCI it would be described as being quasirational. Quasirationality is perhaps the most common form of cognition in that it possesses some analytical features--it is defensible up to a point--and some intuitive features--it is not wholly defensible, or retraceable. Shifts in task properties are thus apt to induce movement from what was highly analytical (highly defensible, highly retraceable) cognition to cognition that is less so. The consequences may be considerable.

For example, if an operator of a system were to be induced by task properties to function in an analytical mode at t0, a change in task properties that moved its location toward the intuition-inducing pole of the TCI would induce the operator to function in a more intuitive fashion.

More specifically, if at t0, the operator were reading data from a display in a sequential fashion with sufficient time to anticipate what the normal readings on each instrument were to be, other things being equal, s/he would be expected to function in an analytical mode. But if at t1, the operator were to be required to read new and unexpected data from several instruments in a very brief time, the theory predicts movement of cognition to a more intuitive mode with the attendant shift in cognitive properties and contingent behavior. One consequence of this movement (as indicated in Table 1) would be the loss of at least some retraceability of the process, and therefore, loss of cognitive accountability on the part of the operator ("I'm not sure why I did that!").

Practical consequences of movement on the cognitive continuum. One difference between static and dynamic tasks, then, is that in static tasks movement on the cognitive continuum is induced by failure, whereas in dynamic tasks movement is induced by changes in the locus of the task on the TCI. A practical consequence of this theoretical prediction is that designers of systems should anticipate which task conditions might produce surprise, which cognitive conditions are apt to occur as a result, whether those cognitive conditions are desirable, and if not, which precautions should be taken. That is, designers should anticipate which changes in task properties are apt to occur over time and which changes in cognition are apt to occur in response to them. Ideally, systems would be designed so that only those cognitive activities considered to be desirable and appropriate would be induced, or permitted to occur. In short, the principal arguments of the theory are that in dynamic tasks (a) the locus

of cognitive activity on the cognitive continuum can be predicted from knowledge of changing task properties, and (b) these changes lead to predictable changes in cognitive activity.

Inducement of Pattern Seeking vs. Functional-Relation Seeking

A further premise of the theory is that any task induces either pattern seeking or functional-relation seeking at any one moment in time; there is no compromise between these two types of cognitive activity, as there is between analysis and intuition. Moreover, as the task changes over time it becomes capable of inducing either form of cognition. If such changes in the task occur, the subject will alternate between (a) seeking patterns and (b) seeking functional relations between surface information and depth states of the system in the effort to reach a judgment or decision regarding the behavior of the system. In short, pattern seeking and functional-relation seeking are types of cognition induced in either-or form by task conditions in contrast to the gradual changes with respect to intuitive and analytical cognition.

There is little need to justify the use of the concept of "pattern seeking" in the present theory; such behavior has been noticed by students of cognition whether scientist (e.g., Gestalt psychologists, modern cognitive psychologists) or engineer (e.g., Rouse, 1983) or lay person. And although in the past psychologists have often argued for one or the other concept of cognition--as if only one type of cognitive activity could exist--it is now clear that human beings and other animals are capable of both. The question is: Which task conditions are apt to induce which type of cognition?

Pattern seeking is induced by (a) displays of information that provide a high degree of perceptual organization (visual, auditory, or otherwise), or (b) displays of information that provide high degrees of conceptual organization, (the presentation of a time-dependent sequence of events, e.g., a story), or (c) circumstances that require the subject to produce coherent explanations of his/her judgment that certain events have occurred, are occurring, or will occur. On the other hand, tasks that induce persons to seek functional relations are characterized by the opposite types of conditions, namely, information that is (a) not perceptually organized, (b) not conceptually organized, and (c) not demanding of immediately coherent explanations. Rather, functional-relation seeking is induced by task conditions that require description and prediction of amounts of variables, for example, velocities of objects.

Asymmetrical translation between patterns and functions. Because patterns contain a high degree of coherence of visual or conceptual materials it is generally easy to form visual images of patterns. But functional relations, particularly if complex, are not so readily imagined. For example, Lusk, Stewart, and Hammond (1987), found that when expert meteorologists were given six numerical data points describing storms in terms of functional relations, they could readily draw schematic diagrams of the behavior of storms over three time periods. But it was much more difficult for the experts to make the opposite inference, that is, from storm images (patterns) to data points.

Task Change and All-or-None Shifts Between Types of Pattern Seeking

A pattern in the "world outside" can be found by an organism if an a priori template for that "outside" pattern previously exists in the cognitive system of the organism. The cognitive activity that permits the organism to match the data (or features) perceived with a template for such data has been called "pattern matching" and "feature matching." Such templates can, of course, be instilled in a cognitive system by training or experience, as, for example, in chess masters, physicians, and other experts. Such templates apparently may also be "wired in" genetically, not only in homo sapiens but other animals as well. Pattern matching is such a pervasive activity that Rouse (1983) has been persuaded that "humans, if given a choice, would prefer to act as context-specific pattern recognizers rather than attempting to calculate or optimize" (pp. 620-621).

Given the present important status of pattern recognition, it is useful to distinguish among three kinds of cognitive templates: (a) arbitrary, based on established empirical relations alone, coherence not required; (b) nonarbitrary, based on established coherence, but not empirical justification; and (c) both coherence and established empirical relations. Each is discussed in turn.

Arbitrary templates. These are generally acquired by years of experience or if taught, acquired by rote memory. Many examples of arbitrary yet empirically valid templates can be found in medicine, weather forecasting, in forecasting economic events, and similar judgments. Arbitrary templates are acquired by the subject only because they have been

found to work; because they lack a theoretical base, however, they lack coherence and are therefore conceptually arbitrary.

When medical diagnoses are based on arbitrary templates, they consist of a list of signs and symptoms that are stored in memory, in textbooks, and now in computer programs that provide valuable assistance to the physician by reducing the memory load imposed by arbitrary templates. Pattern seeking is thus reduced to matching the set of signs and symptoms observed with those sets that have been empirically found to deserve storage. The rather vague words "often," "frequently," "usually," and sometimes, "always" appear in connection with these templates.

Nonarbitrary templates. These templates justify their storage because of their coherence, usually derived from a theory that argues that the elements of the template should, or even must, appear together because some causal relation among the elements is implied. (See Einhorn & Hogarth on probable cause, 1986.) Nevertheless, there will be no demonstrable empirical foundation for storing templates that depend on coherence alone.

Freudian theories of behavior, religious theories or newly formed scientific theories provide ready examples (see Pennington and Hastie, 1981, for the important role of coherence in jurors' arguments over guilt and innocence). Of course, the lack of an empirical foundation does not diminish enthusiasm for seeking patterns of data that match templates that depend on coherence alone; coherence apparently is a powerful motivator for analysis and justification.

Templates that possess both coherence and correspondence. There can be no stronger reason for storing a template than its possession of both coherence and empirical foundations. These are the most desirable templates; seeking patterns to match them is the business of the scientifically or technically trained expert, or otherwise well trained person. Thus, for example, meteorologists will seek various features of a storm cell (e.g., convection, condensation) that should appear together because of the well-founded physical laws that bring them together. (But see Tversky and Gati on "feature matching" in judgments of similarity: Gati & Tversky, 1984; Tversky & Gati, 1982.)

Templates for functional relations. The same three types of templates that occur in connection with pattern seeking can be found in persons' functional-relation seeking. Conceptually arbitrary but empirically justified functional relations are often provided by science (e.g., "empirical regularities") prior to their incorporation in a conceptual framework. Conversely, templates that consist of rules as yet empirically unjustified may find acceptance (and action may be based upon them) because of plausibility that is derived from their fit within a well established network of laws. And, of course, templates that consist of rules that posess both empirical justification and an established place in a coherent network of laws (e.g., rules within Newtonian mechanics, thermodynamics) afford the designer and operator the soundest basis for their judgments and decisions.

There is likely to be a sharp disparity, however, between the designer and the operator in their access to the latter form of template. Designers are apt to apply functional templates of the third type to the design of the depth characteristics of the task-system (actual processes of a plant), whereas operators are more likely to apply pattern templates to the surface displays of the functions embedded in the system. In Rasmussen and Vicente's (1987) terms, the "invisible" processes of man-made systems are apt to be constructed on the basis of the three types of templates of functional relations, whereas the "visible" features of the system are apt to be judged in terms of the three pattern templates--about which more below.

Implications of template differences for judgments in dynamic tasks. It is important to distinguish these three types of templates in dynamic task situations, for changes in task properties may well induce the operator to move from one type to another. Thus, for example, when the display changes from t0 to t1, it may induce an instrument reader to change from a Type III pattern seeker to a Type I or Type II pattern seeker; the display at t1 may no longer exhibit those elements that allow the match for the Type III template. Whether a Type I or II template will be employed will depend on which template training, experience, or lack thereof has instilled in the operator. Would changes in templates make a difference? It certainly could; relying on an arbitrary template that has "worked"--without understanding why it works--versus relying on a template that has never been tested empirically, but "makes sense," would lead to very different actions and very different defensive explanations if failure

followed. ("I don't know why, but we've always done it that way, and it's always worked--until today!")

Task Change and Functional-Relation Seeking

As noted earlier, not all cognitive activity is determined by pattern seeking. Seeking relations, particularly causal relations, between elements of a situation is also a common cognitive activity. But cognitive psychologists seem to have segregated themselves into "schools" that focus on one form of cognitive activity or the other. Hans Berliner was able to break this barrier when he constructed the first computer program to defeat the world champion backgammon player. He described his efforts in a most interesting way:

> The usual way that knowledge is represented in a so-called "expert system" in the field of "Artificial Intelligence" in which this work was done is by a set of rules. A rule is of the form A-->B: "If A is true, then do (or deduce) B". From rules such as this it is possible to go from a set of antecedent conditions to produce very complicated conditions or actions.
>
> Another method of representing knowledge is in the form of mathematical functions. The function A=2B says that, everywhere, A has twice the value B has. A = C/B (where C is a constant) says that A varies inversely as B. Many other basic types of functions are possible, and for certain kinds of knowledge these serve better to represent the basic domain, than knowledge in the form of rules. For instance, the rule "The warmer the weather,

the lighter the clothing you should wear" is much better represented in the form of a function than by a set of rules dealing with various possible temperatures and various items of clothing. (Berliner, 1981, p. 8)

The research carried out within the field of judgment and decision making by Norman Anderson, Berndt Brehmer, Robyn Dawes, Hillel Einhorn, Kenneth Hammond, and Robin Hogarth and many others (see Arkes & Hammond, 1986) rests largely on the implicit assumption that people's judgments are fundamentally based on relations between readily perceived cues (datum) and distal objects or events. Other researchers (e.g., see Kahneman et al., 1982) emphasize pattern-seeking activity, place considerable emphasis on similarity judgments and such concepts as the "representativeness" of a data configuration to some a priori template that the data configuration should represent. (See Hammond, McClelland, & Mumpower, 1980, for a comparative treatment; see also Arkes & Hammond, 1986, for a review.)

The fact that the shift from the Aristotelian tradition that emphasized the importance of object attributes to the modern science of functional relations came as late as the 16th century suggests, however, that functional-relation seeking may somehow be a higher-order cognitive activity than pattern seeking. Thus, it may well be that the first cognitive effort in any problem will be to seek a pattern rather than to seek functional relations, as Rouse (1983) suggests. If so, then a change from task conditions at t0 in which functional relations provide a basis for a judgment about the state of the system, to a new and unfamiliar set at t1 would be predicted to result in a shift to pattern seeking. But much

will depend on task conditions; certain displays may restrict such shifts, a matter to which we turn next.

Relation Between the Cognitive Continuum and Cognitive Types (Pattern Seeking vs. Functional-Relation Seeking)

Intuition or analysis (or quasirationality) can be applied to both (a) pattern seeking and (b) functional-relation seeking. That is, a person can seek a pattern of data to match a template in an intuitive, quasirational, or analytical fashion. Similarly a person can seek functional relations in an intuitive, quasirational or analytical fashion. Because the theory predicts that the locus of the task on the TCI induces the subject to engage in the form of cognition that is located at the same point on the CCI, the theory is indifferent as to whether the subject is engaging in pattern seeking or functional-relation seeking.

Does the Theory Deserve Credence?

The theory presented above has not been well tested as a coherent whole. Nevertheless, it deserves plausibility because it incorporates ideas that have been well tested in a wide variety of circumstances and organisms. Intuitive and analytical forms of cognition are well established behaviors; so are pattern seeking and functional-relation seeking. What is singular to the Cognitive Continuum Theory is that it (a) is rooted in the systems approach and thus takes the properties of the task system as its point of departure, (b) includes the proposition that cognition moves on the cognitive continuum between intuition and analysis, thus offering a place for compromise between the two, and (c) offers equal

status to pattern seeking and functional-relation seeking. The latter (c) deserves further comment.

Theoretical Status of the Pattern-Seeking Approach

It was the advent of the use of the computer analogy as a "model of the mind" that led to the renewal and reinvigoration of the "pattern" as a concept after the battering Gestalt psychology received from the behaviorists. What I have called a "template" in this article (to avoid confusion with any specific approach) has often been described in the literature as a "schema." Despite recent research, considerable conceptual diversity about the concept of a schema remains. For example, it has been described in terms of a list of attributes associated with an object, a network that links concepts in an ordered way, a directed graph, or a "script" that experience has "written" for behavior in frequently occurring circumstances. Although all of these descriptions have received some empirical support, Hastie (1986) points out: "There is no unitary theoretical entity that deserves the label schema theory extant in current information-processing psychology" (p. 21; italics in original).

Designers of systems that require operators to cope with dynamic tasks will, therefore, have to reconcile themselves to current theoretical ambiguity regarding schemas, patterns, and related concepts. Pattern seeking behavior cannot be ignored, but the lack of a theoretical consensus means that the designer will have to consider it in content-specific terms and discover its place by empirical research.

Theoretical Status of the Functional-Relation-Seeking Approach

The discovery of the high predictability of judgments through the use of linear models gave great support to the functional-relation paradigm (see Hammond et al, 1980; Pitz & Sachs, 1984). Further, the failure to find "configural" or "patterned" functional relations in the judgments of many types of experts led most of these researchers to dismiss the idea of "patterns" as mere pretentiousness on the part of experts and others. Indeed, as far back as 1976, Dawes used the term "cognitive conceit" to indicate his view of both pattern seeking and expert judgment.

There is possibly more agreement to be found among the researchers who trust the predictability (and thus utility) of linear models based on functional relations than there is among those who are convinced (along with Rouse, 1983) that pattern seeking is <u>the</u> cognitive concept of choice. This is due to the empirical success of simple models of cognition over 30 years of research. The difference between the two lies primarily in their different aims: The approach based on functional relations has relied on the correspondence theory of truth, whereas the schema-based approach has largely relied on the coherence theory of truth (see Hammond, Hamm, & Grassia, 1986, for an example of the combination of these approaches in the study of experts; see also Hammond, 1986, for the application of this distinction between mathematically oriented operation researchers and empirically oriented decision researchers).

In short, both pattern seeking and functional-relation seeking have long been found to be useful descriptors of cognitive activity. But because researchers within each approach choose testing grounds that exclude the possibility of comparing the advantages and disadvantages of the other approach, research thus becomes highly specific to each approach. Because Cognitive Continuum Theory argues that, over time, the subject moves from one form of cognition to the other, it recognizes the theoretical and empirical legitimacy of both approaches, and thus at present bases its credibility on the cumulative empirical history of both.

The Cognitive Continuum

Cognitive Continuum Theory (CCT) also depends on previous research on intuition and analysis for its credibility. The empirical base for the concept of a cognitive continuum (rather than the usual dichotomy) was produced by Hammond et al. (1987) and Hammond et al. (1986) in which the principle of inducement of corresponding, task-compatible cognition was tested and demonstrated. Obviously, far more needs to be done. What needs to be investigated in the context of dynamic tasks is whether CCT is correct in its prediction that, as task conditions change (i.e., as the locus of a task moves on the TCI) from being, say, analysis inducing to intuition inducing, cognitive activity will move in a corresponding fashion. Irrespective of whether one accepts the plausibility of CCT, systems designers should be explicit about the theory that guides their predictions of cognitive activity of operator judgment, when task conditions change. Dynamic task conditions will almost certainly induce changes in cognitive activity; the behavioral consequences of those changes should be anticipated in the design of the system.

Practical Consequences from the History of Ideas

The two roots of CCT, (a) the recurrent gradual movement between intuition and analysis, and (b) the all-or-none shift from pattern seeking to functional-relation seeking, carry comparable practical significance for the design and operation of complex systems that change over time. In addition, they offer a continuity with our intellectual history; both have roots in the past and it will be useful to at least sketch the relation between their place in yesterday's ideas and today's practical interests. Each is briefly discussed.

Pattern Seeking vs. Functional-Relation Seeking: Aristotle, Galileo, Design Logic, and Operator Logic

The distinction between what de Montmollin and De Keyser (1986) call "design logic" and "operator logic" (see also Brehmer, 1987b) can be illustrated by Thomas Kuhn's (1987) description of his struggle to think about motion as Aristotle did. Kuhn, a physicist trained to think in the tradition of functional relations introduced by Galileo, Descartes, and Newton, could not imagine how an undeniably brilliant man like Aristotle could have such obviously wrong conceptions of motion. Why would Aristotle insist on seeking the pattern of attributes of an object--qualitative physics--rather than seeking functional relations, as in quantitative physics?

It isn't until Kuhn grasps Aristotle's conception of the entire physical system, in which each physical object is seeking to find its natural <u>place</u> (e.g., an acorn is seeking to <u>move</u> to become an oak tree), that Kuhn begins to understand Aristotle's peculiar concepts of the motion of physical objects. The principle is that once the object is identified through its pattern of attributes, then its motion can be understood and predicted. Kuhn's efforts can be set in parallel to those of the designers who build systems on the basis of modern, Galilean science, that is, functional relations, and who must then try to understand the logic of the operator who does not know the science of functional relations upon which the system is built. Just as Kuhn found that he had to pursue Aristotle's entire physical theory in order to grasp his conception of motion, so will designers of systems have to pursue the logic of the operator of the system if they are to build systems that are not susceptible to operator misjudgments. Engineers do not design arbitrary patterns into systems; rather, they design system functions to meet modern scientific criteria. But the cognitive template acquired by the operator may well be an arbitrary one, not only from the operator's point of view, but also from the designer's. In short, the history of science raises the question of the extent to which modern science--functional relations--controls the system on <u>one</u> side of the information display and the science of antiquity--pattern seeking--controls the use of the information on the <u>other</u> side of the display. (See Hammond, Frederick, Robillard, & Victor, in press, for an empirical examination of the alternation between these two forms of logic in the instruction of medical students.)

The Cognitive Continuum: Hume and the Locus of Probable Cause

The cognitive continuum: Hume and the operator's search for causality. The concept of a cognitive continuum replaces the historical idea of a dichotomy between analysis and intuition. The change is important because the concept of a continuum (a) offers a place for quasirational cognition--a form of cognition that lies between the polar types of pure analysis and pure intuition--and (b) permits the anticipation of movement from one place to another on the CCI depending upon changes in task conditions. What are the practical consequences?

Consider, for example, an operator who, at t0 is reading gauges that show the normal, expected pattern. At t1, however, an unexpected event occurs, an event for which the operator has no immediate explanation; that is, no currently held template will accommodate the new configuration of data. If time will permit, an analytical treatment of functional relations--or of the new pattern--can be undertaken to determine the cause of the unexpected display before a response is made. But if time does not permit, the new display will induce in the operator at least some of the intuitive properties of cognition; thus cognition is driven toward intuition. The consequences will be at least a partial loss of awareness and a more rapid response than under analytical conditions, not because of panic, but because new, unaccommodated data will induce more intuitive cognition. When such a compromise has been induced, quasirational cognition that contains elements of both analysis and intuition will control the operator's behavior. Should feedback regarding the outcome of the less than fully defensible response be delayed, cognition will be moved

even further from analysis toward the intuitive pole, and as a consequence, there will be further decrease in cognitive control, awareness and retraceability (see Brehmer, this issue; also 1987b, for effects of delayed feedback). In short, movement on the cognitive continuum from analysis to intuition may have cumulative effects with possibly a disastrous outcome.

One of the most important consequences of recognizing movement on the cognitive continuum can be found in Einhorn and Hogarth's (1986) treatment of David Hume's 18th century conception of judgments of probable cause. In their highly significant article they distinguish among three factors that affect judgments regarding the locus of probable cause: (a) alternatives, (b) background, and (c) cues to causality. Alternatives refer to the size of the set of alternatives to which a person might assign the cause of an event; the fewer the alternatives the greater the likelihood of the cause being assigned to any one of them; background refers to the planner's knowledge and understanding of the situation; and cues to causality refer to the Humean cues of contiguity of time and place. Events that cannot readily be accommodated within a currently held template will increase the likelihood of Hume's cues to causality strongly affecting judgments of the locus of probable cause. For as intuition increases, the set of alternatives is likely to increase (and become unstable), background knowledge will become less useful, and thus coincidental events in time and place will control judgments of the locus of cause. But coincidental events in time may, of course, be nothing more than that; judgments of probable cause under these conditions are therefore likely to be victims of coincidence.

Summary

It should be noted that neither perception nor memory were discussed here, nor was the effect of emotion and stress mentioned. These topics will have to be included in any treatment of judgment and decision making in dynamic tasks that purports to be complete. Despite those serious omissions, the broad theoretical framework presented here is intended to provide a general context for understanding cognition in dynamic tasks to which other factors may be added.

Understanding the behavior of cognition in dynamic task conditions presents a new challenge to students of judgment and decision making because it is entirely new territory. Brehmer (this issue) and I take the position that the explanation of cognition in dynamic tasks should begin with a detailed examination of task systems. But such an examination, we believe, requires that an explicit theory of task systems be constructed and used to name and describe the interrelations of the parameters of such tasks. Such a theory is put forward here. Its principal features include (a) a task inducement principle, (b) a theory of a task continuum in which tasks can be located, and (c) an all-or-none task typology that includes inducement of pattern seeking or functional-relation seeking. In addition, a parallel theory of cognition is described. The practical consequences of the theory for the designers and operators of complex task systems are explained.

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Table 1

Inducement of Intuition and Analysis by Task Conditions

TASK CHARACTERISTIC	INTUITION-INDUCING STATE OF TASK CHARACTERISTIC	ANALYSIS INDUCING STATE OF TASK CHARACTERISTIC
1. Number of Cues	large (> 5)	small
2. Measurement of cues	perceptual measurement	objective, reliable measurement
3. Distribution of cue values	continuous, highly variable distribution	unknown distribution; cues are dichotomous; values are discrete
4. Redundancy among cues	high redundancy	low redundancy
5. Decomposition of task	low	high
6. Degree of certainty in task	low certainty	high certainty
7. Relation between cues and criterion	linear	nonlinear
8. Weighting of cues in environmental model	equal	unequal
9. Availability of organizing principle	unavailable	available
*10. Display of cues	simultaneous display	sequential display
11. Time period	brief	long

* Applicable to surface conditions only.

Table 2

Properties of Intuition and Analysis

	Intuition	Analysis
Cognitive Control	low	high
Rate of Data Processing	rapid	slow
Conscious Awareness	low	high
Organizing Principle	weighted average	task specific
Errors	normally distributed	few, but large
Confidence	high confidence in answer; low confidence in method	low confidence in answer; high confidence in method